FOSSIL PLANTS AS AN AID TO GEOLOGY.

Paleobotany, together with all the other branches of paleontology, admits of subdivision into two lines, or fields of study—the biological and the geological—depending upon the prominence that is given to the one or the other of these subjects. The biological study concerns itself with the evolution of the vegetable kingdom, that is, with the tracing of the lines of descent through which the living flora has been developed. The geological side of paleobotany has two phases, one of which concerns itself with the associations, time relations, and distribution of the plant forms which constitute the successive floras of the geological ages and form an important element in the life history of the earth, while the other is concerned principally with the use of fossil plants as stratigraphic marks, but also with any aid that may be rendered in elucidating the many intricate problems which geology presents. The latter, or geological aspect, is almost exclusively the phase of the subject to which the present paper is devoted.

Before passing to an elaboration of the claims that paleobotany may have as an aid to geology, it may not be out of place to call attention to the fact that the successful use of fossils as stratigraphic marks is, or at least may be, entirely independent of their correct biological interpretation. It makes not the slightest difference to the stratigraphic geologist whether the fossils upon which he most relies are named at all, so long as their horizon is known and they are clearly defined and capable of recognition under any and all conditions. They might almost as well be referred to by number as by name, although, of course, every paleontologist seeks to interpret to the best of his knowledge the fossils that he studies. He may, probably often does, make mistakes in his attempts to

understand them, but from the very nature of the case this must be so. They must all be studied in the light of recent forms, which, in the case of wholly extinct groups, is a matter of great difficulty.

On the other hand, to the historical geologist who makes use of fossils in unravelling the succession of geological events, the correct biological identification is of the greatest importance, for upon this rests his interpretation of the succession of faunas and floras that have inhabited the globe. These principles are tersely stated by Dr. C. A. White in one of his essays on "The Relation of Biology to Geological Investigation."[1] He says: "If fossils were to be treated only as mere tokens of the respective formations in which they are found, their biological classification would be a matter of little consequence, but their broad signification in historical geology, as well as in systematic biology, renders it necessary that they should be classified as nearly as possible in the same manner that living animals and plants are classified."

PRINCIPLES OF PALEOBOTANY.

There are certain broad, fundamental principles upon which the science of paleobotany rests. Some of these are so simple as to be almost axiomatic, while others are less evident and have only recently been recognized. It has been disregard of these principles that, in the past, has often brought paleobotany into disrepute. Each of the departments upon which geology calls for aid has to acknowledge limitations, and so paleobotany has bounds beyond which it can not be legitimately asked to go. But it is confidently predicted that when the evidence has been sifted, and the limitations, as well as the just claims, have been properly adjusted, the evidence derived from fossil plants will be as reliable as that supplied by other branches of paleontology.

One of the most important principles has been admirably

[1] Ann. Rept. U. S. National Museum, 1892, p. 261.

expressed by Professor Ward.[1] It is that "Great types of vegetation are characteristic of great epochs of geology, and it is impossible for the types of one epoch to occur in another." For example, the presence of a dicotyledonous leaf, no matter how fragmentary, is proof positive that the stratum containing it is Mesozoic or younger. It can not possibly be older. Again, the presence of a single scar of Lepidodendron or Sigillaria, when not in redeposited strata, is just as strong evidence that they came from a Paleozoic horizon, since not a single specimen has ever been found later than the Permian.

The application of this principle is often of the greatest aid in geology, for, as frequently happens, the strata of a region have been much displaced and distorted, and it is no uncommon thing to find Paleozoic rocks occupying the positions that should seemingly, normally be taken by Cretaceous or Tertiary strata. The stratigraphy may be so exceedingly complicated as to render it quite impossible to distinguish Paleozoic from Mesozoic strata. Nor can petrography be always depended upon to supply distinguishing marks. In such cases, which are by no means purely hypothetical, a single fossil plant may serve to set at rest all possibility of dispute.

An example of this kind is furnished by the well-known case of the beds of Chardonet in France, "studied by Élie de Beaumont in 1828 and positively referred to the Mesozoic, but in which fossil plants of the genera Calamites, Sigillaria and Lepidodendron were identified by Brongniart."[2] At that time the principle under discussion had not been recognized and Brongniart was "inclined to admit" that these genera might have occurred in the Mesozoic, although long before his death he recognized it and realized that the genera indicated beyond question a Paleozoic age.

Another important principle, bearing upon the limitations of paleobotany, is what has been called the law of homotaxis.

[1] Principles and Methods of Geologic Correlation by means of Fossil Plants. Am. Geol., Vol. IX., 1892, p. 36.

[2] Ward, l. c.

As long ago as 1853 Pictet, in his then celebrated *Traité de Paléontologie*, presented a number of general principles, among them being one, the so-called eighth law, which bears directly upon the present question. It is as follows: "Contemporaneous deposits, or those formed at the same epoch, contain identical fossils. Conversely: deposits which contain identical fossils are contemporaneous." This was modified by Schimper,[1] the celebrated French paleobotanist, who added that deposits "formed at the same epoch, contain floras, if not completely identical, at least homologous, and consequently deposits that contain identical or homologous floras are contemporaneous." But Huxley appears to have been the first (1862) to formulate clearly the objections to this law. He pointed out that while the succession of life in widely separated localities may be shown to have been similar, it by no means follows that the identical elements in these widely separated localities were strictly contemporaneous. To this he applied the term *homotaxis*, which implies that the plants and animals of widely separated places may have had practically the same process of development or succession, yet when the element of time is considered they may have been far from identical. As an example it may be mentioned that the most abundant and typical genus of plants in the Carboniferous rocks of Australia and Tasmania is Glossopteris, a genus which is not represented in rocks of similar age in Europe, but occurs in Upper Mesozoic beds of that region.

This, it will be readily understood, applies to localities widely separated, as for example between continents that are not intimately connected, or that are now and have been for a long geological period separated by insurmountable barriers to immigration, such as oceans and mountain chains. The plants originating within a given area or the ones inhabiting a locality adapt themselves to the environment, and these can only extend their distribution readily to areas in which the conditions are similar. Hence if the particular locality in which a species has been developed is separated from other areas, perhaps as well suited

[1] Traité de Pal. Vég., Vol. I., 1869, p. 100.

to its growth, by a natural barrier such as a lofty, unbroken mountain chain or a broad expanse of water, the chances are against the species finding its way quickly to the remote areas. As an example of this may be cited the flora of the Hawaiian Islands. This flora, exclusive of the species introduced since the discovery of the Islands by Cooke in 1779, embraces 860 species of phanerogams and vascular cryptogams. Of this number no less than 653, or 75.93 per cent. are endemic or peculiar to the Islands. On account of the vast expanse of the Pacific by which the Hawaiian Islands are separated from the nearest land, the flora has been unable to extend its distribution.

It is but reasonable to suppose that similar conditions existed in past geologic ages, but by the obliteration of barriers, such as the shallowing of the water or emergence of direct land connection, the plants may have been enabled to invade new territory, and thus extend from area to area or from continent to continent. If now an examination is made of the remains of vegetation in two or several widely separated areas, the succession will be found to have been the same, but they may not have been strictly contemporaneous.

What now is the deduction to be made since the formulation of this principle regarding the value of paleontologic evidence? Does it immediately follow that all correlations based upon similarity of fossil remains fall to the ground? By no means. It has simply introduced an additional element of caution into the problem of correlation between widely separated areas. And even here it has been, and must continue to be, of the greatest importance, for, as Professor Ward has well said,[1] "What we possess is the general fact that a similar flora once existed in two parts of the world very widely separated, and until some other facts are discovered which complicate and vitiate such a conclusion, it is both safe and useful for the geologist to regard the two deposits as belonging to the same geologic age. There are certain limitations within which this must be true, and when these limitations are recognized the paleontologist may as safely

[1] loc. cit. p. 47.

draw his conclusions as he could before the law of homotaxis had been formulated."

Thus, while admitting the possibility of homotaxial relations existing between the floras of widely separated areas, certain correlations, on the basis of simultaneity, of extensive series of beds in different countries, have stood the test of time. On this subject Sir William Dawson has given important evidence.[1] He says: "I desire, however, under this head, to affirm my conviction that, with reference to the Erian and Carboniferous floras of North America and Europe, the doctrine of 'homotaxis,' as distinct from actual contemporaneity, has no place. The succession of formations in the Palæozoic period evidences a similar series of physical phenomena on the grandest scale throughout the northern hemisphere. The succession of marine animals implies the continuity of the sea-bottoms on which they lived. The headquarters of the Erian flora in North America and Europe must have been in connected or adjoining areas in the North Atlantic. The similarity of the Carboniferous flora on the two sides of the Atlantic, and the great number of identical species, proves a still closer connection in that period. These coincidences are too extensive and too frequently repeated to be the result of any accident of similar sequence at different times, and this more especially as they extend to the more minute differences in the features of each period, as, for instance, the floras of the Lower and Upper Devonian, and Lower, Middle, and Upper Carboniferous."

USE OF FOSSIL PLANTS IN RESTRICTED AREAS.

Turning now from the correlation of strata in widely separated localities, we come to that part of the field in which geology is likely to receive its most valuable aid from paleobotany, viz.: the identification of horizons and their correlation within restricted areas. While the phase of the subject which has just been discussed may be of much importance when the final volume of the geology of the world comes to be written, it can

[1] Geological History of Plants, p. 262.

never, if we are to judge by the recent trend of attempts at widespread correlation, hold the position of importance that correlation within circumscribed areas does. The minor subdivisions of the geological time-standard established for Europe, for example, is found to be of only limited application in North America, and attempts to bring them into complete harmony are little short of wasted energy. But with limited or natural areas the case is far different.

Organic remains are unquestionably of first importance in identifying formations. The study of the mineral composition and lithological characteristics of formations must be abandoned as the sole means necessary for their identification. Recourse must be had to the fossils to set the stratigraphist aright, for as Professor J. W. Judd has said,[1] "We still regard fossils as the 'medals of creation,' and certain types of life we take to be as truly characteristic of definite periods as the coins which bear the image and superscription of a Roman emperor or of a Saxon king." Of the various kinds of such remains fossil plants occupy relatively as important a position as those afforded by most of the other biological groups.

It is by no means uncommon to find that fossil plants are almost the only organic remains present in a formation, but if they are not, the evidence they afford, when properly interpreted, confirms that obtained from other groups of organic life, as the following examples will show.

As an illustration of the first mentioned condition, viz. : that in which plants only are present in numbers sufficient to entitle them to exclusive consideration, the Dakota group offers an exceptionally fine example. This formation is four or five hundred miles wide, more than a thousand miles long and of considerable thickness, yet not a single vertebrate fossil, and hardly ten species of invertebrates have thus far been detected throughout its vast extent. The Dakota flora, however, is one of the most extensive and thoroughly known fossil floras. According to Lesquereux[2]

[1] Nature, Vol. XXXVII., 1888, p. 426.

[2] Flora of the Dakota Group, p. 14.

460 species have been described from this formation, of which number no less than 394 are peculiar, that is, have never yet been found outside of it. A very large number of these plants are so characteristic that their discovery in strata of unknown age would settle at once their reference to this horizon. An illustration of this is just at hand. A single dicotyledonous leaf was some time ago described,[1] under the name of *Sterculia Drakei*, from the upper sandstone of the Tucumcari beds near Big Tucumcari Mountain, New Mexico. This plant has lately[2] been referred to as the only dicotyledon known from the Trinity beds of the Comanche series, a reference that is, so far as we know, highly improbable, for Fontaine, in his descriptions of all of the plants now known from these beds[3] finds no trace of dicotyledons. A glance at the figure of the Tucumcari plant suffices to show that it is *Sterculia Snowii*, a well-known, very abundant, and characteristic plant of the Dakota group. This leaf, together with what is now known of the position of the rocks containing it, is amply sufficient to settle the age of this portion of the Tucumcari sandstone, a conclusion agreeing perfectly with the results several times set forth by Professor R. T. Hill from stratigraphic and paleontological grounds. The Potomac formation furnishes a parallel example. This series of beds, extending in almost unbroken line from New Jersey to Alabama, contains a known flora of 737 species, over 80 per cent. of which are peculiar.

An example of the complete accord existing between fossil plants and other organic remains in determining age is offered by the Trinity Division of the Comanche Series of Texas, the flora of which, so far as known, has recently been worked out by Fontaine.[4] The particular beds in this series, from which the plants came, have been named the Glen Rose or alternating strata, by Professor R. T. Hill, and their age determined by marine invertebrates, as Neocomian or basal Cretaceous. The flora consists of twenty-

[1] Geol. Survey of Texas, 3d Ann. Rept., 1891, p. 210.

[2] Am. Geol., Vol. XII., 1893, p. 327.

[3] Proc. U. S. National Museum, Vol. XVI., 1893, p. 261–282.

[4] Op. cit., p. 281.

three species of plants characteristic of the lower Cretaceous, and appears to find its closest resemblance in the older portion of the lower Potomac. Professor Fontaine's results are summed up as follows: "The Glen Rose or alternating strata, in which the fossil plants are found, contain an abundant marine fauna, from the evidence of which Professor Hill had concluded that its age was Neocomian or basal Cretaceous. No fossil plants had hitherto been found in the Comanche series, and the evidence of its age was derived wholly from the animal remains. The discovery of plants in it was, then, of special importance, for it enabled us to compare the evidence of the plant-life with that of the animal life. It is interesting to find so close an agreement. This agreement adds one more proof of the value of fossil floras in fixing the age of the strata in which they are found."

The age of the strata exposed at Gay Head, on the western end of Martha's Vineyard, has been the subject of discussion and speculation by geologists for nearly or quite a hundred years, and the question has only recently been settled. In general the strata have been correlated with the similarly appearing strata of Alum Bay in the Isle of Wight, the position of which is fixed as middle Eocene. It is true that certain Cretaceous shells had been found, but they were not in place, and so intermingled with recent forms, that it was concluded that the age could hardly be other than lower or middle Tertiary. As late as 1889 Professor N. S. Shaler[1] decided, upon purely stratigraphic grounds, that "this part of the Tertiary series is certainly of later Miocene or Pliocene age.

In 1890 Mr. David White visited Martha's Vineyard, and was fortunate enough to find and collect a considerable series of fossil plants from the strata in question. The results of this study[2] showed beyond all doubt that they were of Cretaceous age, many being identical with the plants of the Amboy clays of New Jersey. "The Gay Head flora," Mr. White concludes, "indi-

[1] Seventh Annual Report U. S. Geol. Survey, 1885-6, p. 332.

[2] Cf. Am. Jour. Sci., Vol. XXXIX., 1890, pp. 93-101.

cates an age certainly Cretaceous, and probably middle Cretaceous."

Here, then, is an example of the value of a few fossil plants in determining the age of a series of beds where a hundred years of study from the stratigraphic side had failed to accomplish conclusive results.

The flora of the so-called Laramie beds of the Rocky Mountain region has also been the subject of much discussion and controversy. By certain of the older writers it was referred to the Tertiary, by others to the Upper Cretaceous. Recent investigation has shown, however, that several distinct horizons were embraced in what has been known as the Laramie. The tendency appears to be to restrict the term "Laramie," at least in the Colorado district, to the lower or older beds, and accordingly the Post Laramie beds have been differentiated and given independent names. As fossil plants are the most abundant organic remains present in this series of strata, their bearing on the question of the age and differentiation of the beds is important. No dependence can be placed on the earlier determinations of the distribution of the plants, for the reason that the different horizons had not then been distinguished, and the plants are often recorded from a locality at which several of the horizons are present and plant-bearing. It has been necessary to go over all the original material and determine by studying the matrix, and by duplicate collections, the actual horizon to which they belong. In this way the status of 285 species now known to occur in these beds has been settled. In Colorado and New Mexico, the only area in which the interrelations have yet been worked out, it appears that there is a flora of 165 species, of which number 62 belong to the true Laramie and 103 to the Denver beds, and with only 7 species common to both. This proves beyond question that the Laramie and Denver beds are distinct, and that they possess, in certain clearly defined species of fossil plants, readily recognizable stratigraphic marks.

The deductions made from this datum point, viz.: the thorough study of the flora of the Colorado Laramie and allied

formations, are already important. Of these two or three examples may be cited.

The Post-Laramie beds of Middle Park, Colorado, have been made the subject of an investigation by Mr. Whitman Cross. After reviewing historically the opinions of various writers as to the age of these beds, he discusses exhaustively the results of recent work in this field. He reviews the fossil flora at length, correcting many obvious errors of locality and horizon into which the early collections had fallen, and finally presents a revised list of the plants known certainly to have come from the Middle Park beds. In the light of the revisions of the Laramie and Denver floras, nearly 75 per cent. of the species enumerated in this list are found to be common to the Denver beds. The complete agreement of the paleobotanical with the other geological evidences is well shown in conclusions of Mr. Cross, which are as follows: "The unconformable relationships, lithological constitution, and fossil flora all indicate the equivalence of the Middle Park and Denver beds. No evidence seems to indicate any other correlation."[1]

The Laramie and Post-Laramie beds of Montana have been studied by Mr. W. H. Weed.[2] His paper gives an account of a series of beds heretofore embraced within the Laramie, and covering the greater portion of the State of Montana east of the Rocky Mountains. It is shown stratigraphically that the thickness of some 13,000 feet of strata belong to three formations: the Laramie, the overlying Livingston, and the higher Fort Union beds.

Fossil plants occur in all three of these formations, and from their study it is made clear that the Livingston beds occupy the same position in Montana, with reference to the Laramie, as do the Denver beds in Colorado. Of 22 species of plants found in the Livingston beds no less than 17 are found either exclusively in the Denver, or have their greatest development in this formation.

[1] Proc. Colorado Scientific Soc., 1892, p. 26 of reprint.

[2] Bull. U. S. Geol. Survey, No. 105.

Large numbers of huge vertebrate remains, only known from "The Laramie of Wyoming," fortunately have fragments of fossil plants adhering to them, from the study of which important light will be thrown on the age of the beds in which they are contained.

Along the Missouri river in the vicinity of Great Falls, Montana, there is exposed a considerable thickness of mainly brown, sandstone rocks. They have been eroded by the river into more or less of a cañon, and are the material in which the falls have been developed. From their lithologic appearance, but mainly upon stratigraphic grounds, these rocks have been referred by geologists to the Dakota group. On going down the river they disappear under the Fort Benton shales, and are consequently in the stratigraphic position of the Dakota, but the recent discovery of plant-beds near Great Falls has shown the impossibility of such reference. The plants are typically lower Cretaceous, and have been positively identified by Newberry with the Kootanie of Canada. By this a part at least of the so-called Dakota goes to the lowest Cretaceous.

In a similar way a part of the supposed Dakota of the Black Hills has been shown by Professor Ward,[1] purely on paleobotanical evidence, to belong to the lower Cretaceous.

The Foreman beds in the Taylorville region, Plumas county, California, were determined to be of Rhætic age from the fossil plants, a determination agreeing perfectly with the stratigraphy.[2]

The copper mines near Abiquiu, New Mexico, were identified as Triassic by the plants found in and about the roof of the openings.[3]

The employment of fossil plants in practical mining exploitation is well shown by the results obtained by Grand' Eury and Zeiller in Southern France.

In the Department of Gard the mining of coal is one of

[1] Journal of Geology, Vol. II., No. 3, pp. 250–266.

[2] DILLER : Bull. Geol. Soc. Am., Vol. 3, p. 373.

[3] FONTAINE & KNOWLTON : Proc. U. S. Nat. Mus., Vol. XIII., 1890, p. 282–285. NEWBERRY : Rep. Expl. Ex. in 1859 under Macomb. Wash., 1876, p. 140.

the most important industries. In this district there are a number of veins of workable coal which have been formed at different epochs. These veins are separated from each other by barren strata of varying thickness, and are always accompanied by certain characteristic plants, especially ferns and allied forms.

In the valley of the Grand' Combe there are a number of coal openings, among which may be more especially distinguished those of the Sainte Barbe and Grand' Combe. M. Zeiller, the engineer-in-chief of the mines, from a study of the fossil plants which accompany the two layers, determined that the first deposit, viz : that of Sainte Barbe, was older than the other. With this knowledge in his possession, M. Zeiller did not hesitate to counsel the company that by sinking a shaft at a place called Richard, just outside of the valley of the Grand' Combe, they would reach a new seam of coal corresponding to the Sainte Barbe. The shaft was sunk for 400 meters, but as only barren strata were encountered it was abandoned, and it was reserved for Grand' Eury to prove the correctness of Zeiller's prediction.

Grand' Eury, in a general study of the coal basin of Gard by means of fossil plants, determined that the coal of Sainte Barbe was deposited at the same epoch as that of Bessèges, from the fact that the same plants occurred at both localities. In the same manner he proved that the coal of Grand' Combe was of the same age as that of Gangières, but he also found that between the beds of Bessèges and Gangières there was a barren series of strata approximating 600 meters in thickness. It therefore became evident that the shaft at Richard had been abandoned too hastily, and work was again prosecuted, and at a depth of 731 meters the vein of coal, 4.80 meters thick, corresponding to the Sainte Barbe, was reached.

STUDY OF FOSSIL PLANTS BY MEANS OF INTERNAL STRUCTURE.

By far the larger proportion of fossil plants are preserved in the form of impressions or casts of leaves, fruits, stems, etc., only comparatively few having the internal structure so preserved as

to admit of their study under the microscope. The parts usually exhibiting internal structure are stems, branches, roots, and other normally hard organs, yet in exceptional. cases every part of the plant, including the leaves, buds, and flowers, are so perfectly preserved that they may be as successfully studied as though living. An example of this kind is afforded by the Carboniferous groups of Cordaites, found in a state of silicification in central France.

Plants that are so preserved as to retain their internal structure, admit of closer study and characterization than is usually attained for other plant organs. So valuable is this method that Professor W. C. Williamson, the distinguished English paleobotanist, was led to say[1] "that no determinations respecting fossil plants can have much absolute value save such as rest upon internal organization ; that is the basis upon which all scientific recent botany rests, and no mere external appearances can outweigh the positive testimony of organization in fossil types." Therefore, when it is possible to obtain plant remains with the internal structure preserved, it may be safely set down that they will afford valuable and reliable data for stratigraphic identification.

The study of the internal structure of fossil plants is yet young in North America, and while a broad field remains for future investigation, enough has alreadv been accomplished to show its value. A few examples may be cited :

In 1888, *Araucarioxylon Arizonicum* was described from the Trias (Shinarump group of Powell) of New Mexico. The same species has been found characteristic of the Trias of North Carolina[2] and of the copper mines near Abiquiu, New Mexico.[3]

In his paper on the geology of Skunnemunk Mountain, Orange county, New York,[4] Professor C. S. Prosser relies upon

[1] On the Organization of the Fossil Plants of the Coal Measures. Roy. Soc., London. Phil. Trans.. Vol. 161; 1871; p. 492.

[2] RUSSELL : The Newark System, p. 29.

[3] FONTAINE and KNOWLTON : Notes on Triassic plants from New Mexico. Prcc. U. S. Nat. Mus., Vol. XIII., 1890, pp 281–285.

[4] Trans. N. Y. Academy Science, Vol. XI., June, 1892.

the fossil plants, especially *Nematophyton crassum* known from the study of its internal structure, to prove the Middle Devonian age of that part of the geological section.

Certain well-defined species of fossil wood are characteristic of particular horizons, as for example *Cordaites Ouangondianus* (Dn.) Göpp., which is confined to the Middle Erian (Devonian); *C. Halli* (Dn.) Kn., and *C. Newberryi* (Dn.) Kn., are confined to the Hamilton Group; *Dadoxylon annulatum* Dn., found only in the middle coal-measures, etc.

SUBSIDIARY USE OF FOSSIL PLANTS.

Among the many relatively subsidiary problems connected with the application of paleobotany to geology, the use of fossil plants as tests of past climate occupies an important place. Plants are unable to migrate like animals when the temperature of their habitat becomes unfavorable, and they must either give way, or adapt themselves gradually to the changed conditions of environment. Hence, fossil plants have always been accorded first place as indices of past climates. "They are," as Dr. Asa Gray has said, "the thermometers of the ages, by which climatic extremes and climate in general through long periods are best measured." [1]

The wide geographical distribution and similarity of appearance of Paleozoic plants, especially coal-measure plants, argues beyond question a uniformity of climatic conditions. The absence of rings of growth in the Carboniferous conifers shows, as long ago pointed out by Witham, that the seasons, if such they could have been called, were either absent or not abrupt, and it is not until the Trias is reached that the clearly defined rings of growth bear indisputable evidence of the existence of seasons.

"Heer, as a result of his examination of the Swiss Tertiary plant-beds, is led to the interesting conclusion that in certain cases it is possible to detect the regular recurrence of seasons by the constant association in the same strata of fruits or leaves

[1] The Nation, No. 742, September 18, 1879.

of plants whose living representatives are known to agree closely in their period of vegetation."[1]

Fossil plants may also, in certain cases, be used to indicate the character of the water in which the deposits were laid down. Thus, the finding of an abundance of marine diatoms in an undisturbed formation is proof that they were deposited in salt water, and the finding of diatoms only known in connection with hot springs is equal proof of former thermal activity. As an example of the last may be mentioned the finding of a large number of species of diatoms in beds of infusorial earth in Utah that are now found living in a hot spring (temperature 163° F.) in Pueblo Valley, Humbolt County, Nevada, showing that the fossil specimens must have been accumulated in a hot lake of about the same temperature.[2]

It is quite commonly argued that during Carboniferous time there was present such a large amount of carbon-dioxide that it produced a thick veil, hiding or at least largely obscuring the direct sunlight. This extreme view is not wholly sustained by fossil plants, for the presence of strongly developed palisade parenchyma in certain leaves, as in Cordaites and many ferns, which can only be formed in direct sunlight, shows conclusively that there must have been at least gleams of sunlight penetrating the so-called veil.

LEGITIMATE FIELD OF PALEOBOTANY.

Before leaving the subject it may be well to point out some of the responsibilities resting with the geologist who would avail himself of paleobotanical aid in the determination of horizons. In the first place, if it is worth while to ask an opinion of the paleobotanist, it is surely worth while for the geologist to spend time enough when making the collection he would submit, to procure at least a fair representation of the fossil flora of that horizon. To expect the paleobotanist to unravel a stratigraphic problem that has perhaps puzzled the trained stratigrapher and

[1] A. C. Seward. Fossil Plants as Tests of Climate, p. 20.

[2] Am. Journ. Sci., 3d ser., Vol. IV., 1872, p. 148.

petrographer, by the examination of a mere handful of specimens gathered hastily as a "last thought," is asking too much! There is a limit to what can legitimately be expected of paleobotany, just as there is a limit to all knowledge.

Again, it has frequently been a practice among geologists to submit a collection of fossil plants without indication of the specific information desired or even of the locality whence the specimens came. This is done presumably with the idea that the paleobotanist, being unembarrased with previous information, would be the better able to give an unbiased opinion. This again is wrong, and under such circumstances the paleobotanist would be amply justified in declining to express an opinion. Unless he can be placed in possession of all the information known to the geologist, or, what is better, have an opportunity of examining the relations of the horizons himself, he should hesitate before passing judgment. Of course, as pointed out under the discussion of principles, certain broad conclusions may be made instantly, such as the presence of dicotyledons proving an upper Mesozoic age, or Lepidodendra and Sigillaria arguing a Paleozoic age. These, however, are not usually the problems presented, but close questions of age, as, for example, the Miocene or Pliocene age of the auriferous gravels of California.

It has been argued by many, especially botanists and geologists, that it is undesirable to give names to fragmentary and seemingly indeterminable plant remains. When a definite name is given it implies, it is argued, a more exact knowledge than is often times possessed; a view that in many cases is undoubtedly correct. But the name is given, when the fossil cannot be made out satisfactorily, for purely practical reasons. It embodies, or should, the best possible judgment as to its nature and systematic position, and serves as a convenient basis of future mention of it without tedious circumlocution.

The foregoing examples have been given somewhat in detail, for the purpose of showing what has already been done with fossil plants, and to indicate the lines along which, it is hoped, increased assistance will be rendered geology in the future. These

examples have designedly been confined almost exclusively to North America, and while additional ones might have been given within this area, but more particularly in other countries, enough has been presented to indicate that paleobotany may be relied upon to supply a series of stratigraphic marks in every way as reliable for the cases they cover as those supplied by any of the other branches of paleontology.

F. H KNOWLTON.